

THE OXIDATION OF PYRITES AS A FACTOR IN THE SPONTANEOUS COMBUSTION OF COAL

BY

SHEO-HEN LI

B.S., University of Illinois, 1922

M.S., University of Illinois, 1923

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The Oxidation of Pyrites as a Factor in the Spon- taneous Combus- tion of Coal¹

By S. H. Li with S. W. Parr

UNIVERSITY OF ILLINOIS, URBANA, ILL.

Recent studies on the oxidation of coal seem to prove conclusively that oxidation proceeds very rapidly after a temperature of 70° or 80° C. has been attained, and quickly reaches the autogenous stage, while at normal temperatures the oxidation is not ordinarily of sufficient magnitude to generate heat. The question therefore arises as to the source and causes for an initial rise in temperature which is responsible for advancing the mass to the danger point.

It is well known that coals that are very low in sulfur content are subject to this initial heating, and it is altogether probable that sulfur is not always the source of difficulty. Under certain conditions sulfur in the pyritic form may set up oxidation processes which may account for this initial heating. The present studies proceed along the line of pyritic sulfur activity from the standpoint of fineness of division, form of crystallization, whether pyrite or marcasite, and the effect of bacterial and catalytic agents which might possibly be present in the original substance. The most pronounced indication of oxidation was secured in the case of coals which started out with a high percentage of textural moisture which was allowed to be replaced by oxygen, and the most active condition at normal temperatures was secured with mixtures of certain types of clay.

¹ Presented before the Division of Gas and Fuel Chemistry at the 71st Meeting of the American Chemical Society, Tulsa, Okla., April 5 to 9, 1926.

THE subject of spontaneous combustion of coal has been a topic of much discussion and experimentation. Owing to the complicated nature of the coal substance and the many factors that enter into the heat-producing reactions, no definite conclusion has been reached, especially with respect to the source of initial heating. Ample evidence is available to show that coal does heat in the presence of oxygen at elevated temperatures, say 80° C. or higher; yet this does not cover the fundamentals of the problem. It is unquestionable that coal piles will occasionally take fire in the absence of extraneous sources of heat and the question arises as to the initial causes for starting the heat increments. Presumably, the initial heat must be associated with the oxidation of either the carbonaceous materials or with the sulfur content of coal.

Some coals with very low sulfur content may ignite, yet this does not mean that the pyrites is not a factor in other cases. Previous investigations^{2,3} have shown that any form of pyrites, when finely ground, will absorb oxygen and enter into heat-producing reactions. Furthermore, owing to its low specific heat, pyrites will heat up faster than coal and it may act as booster for further oxidation activities. It is the primary purpose of this investigation to determine the role of pyrites in the initial heating of coal. Chief attention is given to the conditions which promote its oxidation at ordinary temperatures.

Experimental Procedure

The oxidation of mineral pyrites or the sulfur in coal was determined by measuring the amount of increase of sulfate content before and after the oxidation. It was found from preliminary experiments that when a coal and pyrite mixture was oxidized in a stream of oxygen saturated with moisture the products of oxidation were retained in the mixture as sulfates regardless of the intermediate steps. There was no loss of sulfur due to volatile gases, although when the mineral pyrites was oxidized alone at 100° C. in the same way a small proportion of sulfur dioxide gas passed over. Thus the increase of sulfate content in coal-pyrite mixture is an accurate measure of the degree of oxidation of the pyrites.

The oxidation of pyrite-coal mixture was carried out in an apparatus devised by Prof. J. White,⁴ of Rose Polytechnic Institute. The principle and operation are self-explanatory from the sketch as shown in Figure 1. Its essential feature is a double-walled tube with ends closed with corks. The space between the two tubes is filled with water vapor generated from a flask on a hot plate. The upper part of the apparatus is provided with a return condenser. The condensed water returns to the flask through a by-pass.

² Winmill, *Trans. Inst. Min. Eng. (London)*, **51**, 500 (1916).

³ Graham, *Ibid.*, **67**, Pt. 2, 100 (1924).

⁴ *J. Franklin Inst.*, **173**, 201 (1911).

In this apparatus the substance to be oxidized can be kept at any desired temperature for a long period of time by using different liquid heating media. Oxidation was carried out at two different temperatures, one at 100°C ., using water as a heating medium, and the other at room temperature, which varied from 23° to 27°C ., designated as 25°C . At room temperature a single glass tube was used instead of the double-walled heating apparatus, other arrangements being the same.

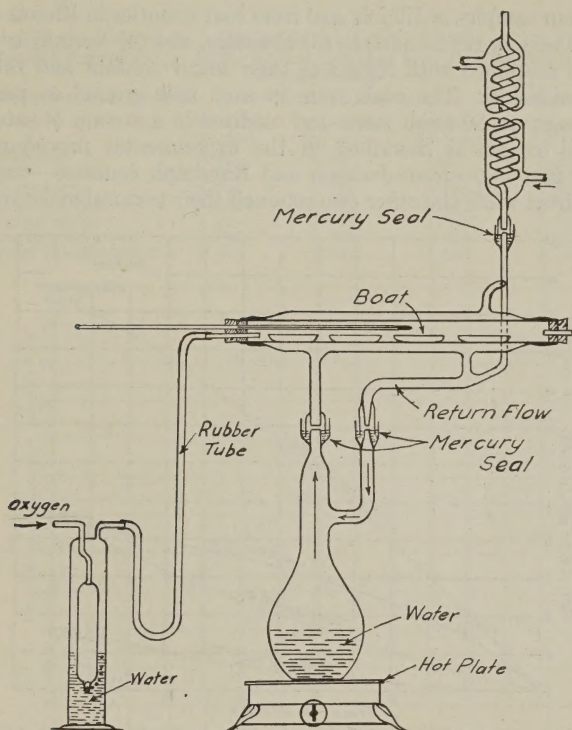


Figure 1

Samples of 5 grams each of coal or coal-pyrite mixture, accurately weighed out, were put in small aluminum boats and placed in the inner tube. Oxygen, saturated with moisture by bubbling through a wash bottle containing distilled water, was passed over the coal and discharged into the atmosphere, since the oxidation of the coal substance is disregarded. The wash bottle containing distilled water, in the case at 100°C ., was placed near the hot plate to keep it fairly warm and thus enable the oxygen to carry plenty of moisture when it enters the apparatus. After a certain time of oxidation duplicate samples of 5 grams each were transferred to large beakers and their sulfate content determined. The percentage was calculated on the basis of total sulfur, deducting the sulfate originally present.

The method used for the determination of sulfate was that worked out by Powell and Parr.⁵ The method consists of extracting the coal with 3 per cent hydrochloric acid at 60° C. for 40 hours. After filtration the sulfate is determined as usual. Duplicate samples were run in all the cases and a good check, variable within 0.01 per cent, was frequently obtained.

Oxidation of Sulfur Originally Present in Coal

Four samples of Illinois coal from four counties in Illinois—(1) Jackson, (2) Randolph, (3) Franklin, and (4) Vermilion—were examined with regard to their sulfur content and rate of oxidation. The coals were in each case ground to pass through an 80-mesh sieve and oxidized in a stream of saturated oxygen as described in the experimental procedure. The first two—from Jackson and Randolph counties—were air-dried while the other two retained their textural moisture.

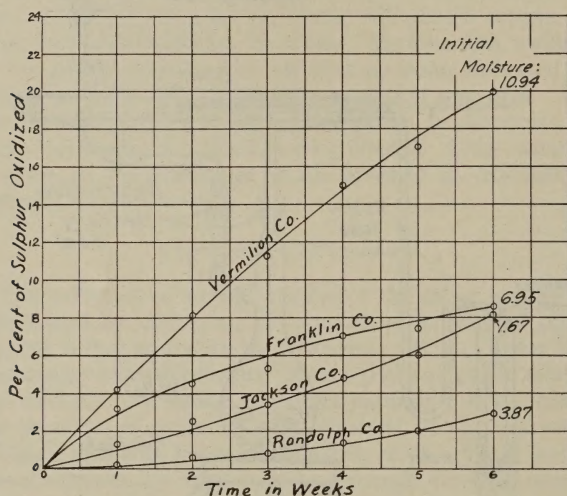


Figure 2—Oxidation of Sulfur in Illinois Coals at 25° C. in Oxygen Saturated with Moisture

The results as represented in Figures 2 and 3 show that (1) the rate of oxidation of sulfur in air-dry coal varies with the temperature; (2) coals with high initial moisture may have a high rate of oxidation of sulfur at normal temperatures. From these results it seems desirable to study the factors which influence the rate of oxidation.

The difference in the rate of oxidation of the sulfur in coal may be due to several causes, as (1) the presence of certain readily oxidizable forms of pyrite in some of the samples (to be discussed in a later paragraph); (2) the initial textural moisture content in the samples; and (3) some samples contain more of the very finely divided pyrites. To prove the last point a sizing test was made by sieving the samples

⁵ University of Illinois, Eng. Exp. Sta., Bull. 111 (1919).

through screens of different sizes with sulfur content determined on each portion. The results of this test, together with related factors, are given in Tables I and II.

Table I—Distribution of Total Sulfur with Reference to Fineness of Division

	Through 80 on 140 mesh Per cent	Through 140 on 200 mesh Per cent	Through 200 on 325 mesh Per cent	325 mesh to dust size Per cent
Vermilion	5.09	24.20	26.86	43.85
Franklin	12.59	25.09	32.85	29.47
Jackson	9.49	19.55	21.80	49.16
Randolph	8.44	29.31	26.10	36.15

Table II—Proximate Analysis of Samples of Illinois Coal, with Special Reference to Their Sulfur Content and Its Distribution in Various Forms

(Organic sulfur equals the total sulfur minus sulfate sulfur plus pyritic sulfur)

	Vermilion Per cent	Franklin Per cent	Jackson Per cent	Randolph Per cent
Moisture	10.54	6.95	1.67	3.87
Ash	12.26	5.05	8.66	13.43
Total sulfur	3.748	1.384	5.173	2.590
Sulfate sulfur	0.071	0.022	0.132	0.012
Pyritic sulfur	1.914	0.412	3.165	0.596
Organic sulfur	1.763	0.950	1.876	1.982
Total oxidizable sulfur	3.677	1.362	5.041	2.578

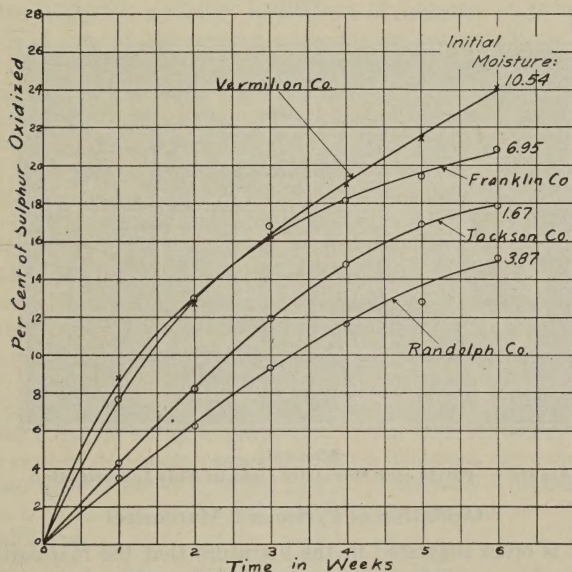
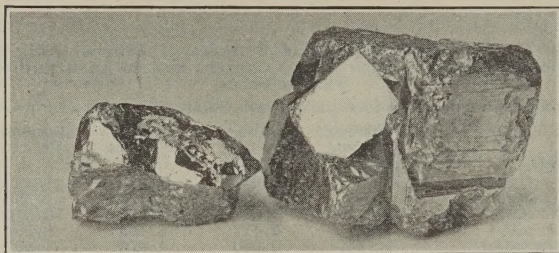


Figure 3—Oxidation of Sulfur in Illinois Coals at 100° C. in Oxygen Saturated with Moisture

The fineness factor enables us to explain the behavior of sulfur only in a general way. Vermilion and Jackson County coals have a high percentage of sulfur in the fine sizes, yet the latter did not show nearly so high a rate of oxidation as the former. The difference may be explained by the fact that Jackson County coal contains a considerable amount of sulfate sulfur which probably is very finely divided, leaving the actual oxidizable sulfur in the coarser portions.

The sulfur in Jackson and Vermilion County coals have about equal rates of oxidation at 100° C.; yet the latter is considered much more in danger of combustion in storage than the former. The Vermilion coal contains a high percentage of sulfur, which, most important of all, has a high rate of oxidation at ordinary temperatures. Vermilion coal also seems to be more fragile than the other samples examined. This would increase its danger of firing in storage.



Pyrite.



Marcassite

Figure 4—Pyrite and Marcassite Used in This Investigation

Oxidation of Pyrite and Marcassite

It is often suggested in the literature that the marcassitic form of iron sulfide is much more readily oxidized than the pyritic, yet there is no experimental evidence as to what extent this is true. Graham,³ in his study on the absorption of oxygen by different forms of pyrite, found that marcassite did not have nearly so high a rate as one sample of massive pyrites. He interprets his result as due to size. He said that "the difference observed between marcassite and the Cornwell pyrite may possibly be due to size, since microscopic examination of the two powders rather indicated that the latter, when crushed to pass through a 200-mesh sieve, formed finer particles than the former."

In view of this uncertainty it seemed advisable to carry out more work along this line. One sample of cubic pyrite and one of marcasite were examined for this purpose (Figure 4). The sample of pyrite, obtained from Leadville, Colo., came in as perfect cubes with bright, brassy surfaces evidently untouched by oxidation. The marcasite was obtained from the geology department of the University of Illinois, its source being unknown. The marcasite had a needle-like crystalline structure with dull grayish tin color, and showed slight oxidation on the surface. The minerals were identified by Penfield's method⁶ of distinction and shown to be correctly designated. The minerals were pulverized to the same degree of fineness and mixed in the proportion of 3 per cent of minerals with Randolph County coal and oxidized with saturated oxygen at two different temperatures—100° and 25° C. The difference between the sulfate content of the coal-pyrites mixture and that of the Randolph County coal when oxidized alone gives the rate of oxidation of the minerals. The results are graphically represented in Figures 5 and 6.

Marcasite has a slightly higher rate of oxidation at 25° C., while at 100° C. the reverse is true for the sample ground to pass 325 mesh. This may be due to the fact that the increase of temperature has a slightly greater effect on the oxidation of pyrite than of marcasite. For the samples ground to pass through 140- and caught on 200-mesh sieve, the two curves are in general agreement when they were oxidized at 100° C., the pyrite having slightly higher rate for the first part of the experiment, while later the condition is reversed.

This slightly higher rate of oxidation of marcasite at 25° C. does not necessarily indicate that it is more readily oxidized than pyrite. It is believed to be due more to its highly fragile nature, and to more fine material being produced during grinding. In samples of pyrite and marcasite ground to pass through a 200-mesh sieve, it was found that the latter contains a higher proportion of the finer particles; 92 per cent of marcasite passed through a 325-mesh sieve compared with 71 per cent of the pyrite. This ratio is probably also true in that proportion which passes through the 325-mesh sieve.

Factor of Fineness of Division

The effect of fineness of division was studied by separating the same sample of pyrite used in the previous experiment into four portions, mixing with Randolph County coal, and oxidizing each in saturated oxygen.

From an examination of the results (Figure 7) several features are noticeable. The rate of oxidation seems to be a function of the size of particles, the oxidation of pyrite being nearly a linear function of its surface area.

⁶ Brush and Penfield, "Descriptive Mineralogy," 15th ed., 1898, p. 252.

We may assume that the surface areas of two powders of certain unit volume are in inverse ratio to the average diameter of their grains, as suggested by Purdy,⁷ if we assume first that the distribution of each portion is graded uniformly. It will be noted that the ratio of the reciprocal of the average diameters of the different portion and that of the percentage oxidation of the pyrite for 6 weeks are quite close. The relationship between the rate of oxidation, temperature, and the size of the particle can be expressed mathematically as follows:

$$R = \frac{T}{D} \cdot K$$

where R = rate of oxidation of pyrites

T = temperature in °C.

D = diameter of the particles

K = a constant; depends upon form of pyrite considered

This equation indicates in a general way that the rate of oxidation is directly proportional to the temperature and inversely proportional to the diameter of the particles.

Probable Catalytic Oxidation

We have learned from the above experiments the nature or behavior of the pyrites alone when present in coal. However, the presence of certain substances or catalytic agents might affect the rate of oxidation of pyrite to a great extent. The following substances have been studied for their possible catalytic action on the oxidation of pyrites by mixing them with Jackson County coal and oxidizing the mixture in saturated oxygen at room temperature: (1) Indiana clay, found underneath the kaolin deposit in Lawrence County, Indiana; (2) Tennessee ball clay; (3) coal highly saturated with oxygen; (4) sulfur oxidizing bacteria; (5) carbonated calcite water and common salt; and (6) mother of coal.

The first three substances showed considerable catalytic action while the last three gave negative results. A word might be said about the Indiana clay.

Logan⁸ has described some experiments with black clay which was found underneath the kaolin deposit in Lawrence County, Indiana. This clay was shown to contain sulfur bacteria of some species closely related to that of the genus *Beggiatoa*. To this type of organism was ascribed the mineral alteration from feldspar to pure kaolin. Some of this clay was obtained from the Gardner mine in order to test its possible action toward pyrites. The clay as received was yellowish rather than black, had fine texture, some plasticity, and granular structure.

The so-called sulfur-oxidizing bacteria were a pure culture, *Thiobacillus thio-oxidans*, obtained from Dr. Waksman of the New Jersey Agricultural Experiment Station. The bacteria culture was kept in a liquid mixture⁹ containing some sulfates

⁷ *Trans. Am. Ceram. Soc.*, **7**, Pt. III, 441 (1905). See also Cushman and Hubbard, *J. Am. Chem. Soc.*, **29**, 589 (1907).

⁸ Dept. of Conservation, State of Indiana, *Publication* **6**, (1919).

⁹ Waksman and Joffe, *Soil Sci.*, **12**, 475 (1922).

and elementary sulfur. This culture was supposed to oxidize mainly elementary sulfur. Thus so long as the mixture contains any elementary sulfur, it would have no effect upon the oxidation of pyrite. The curves in Figure 8 show the result of this series of tests.

Indiana clay has the greatest effect among the substances studied. In the presence of this clay the rate of oxidation of the sulfur in coal was about doubled. The catalytic action of Indiana clay was also tried on Vermilion County coal. The part of the total sulfur in this coal oxidized in 1 week was 4.19 per cent and 8.15 per cent in 2 weeks, while in the presence of the clay they were increased to 8.06 and 12.53 per cent, respectively. The latter rate is practically equal to that at 100° C.

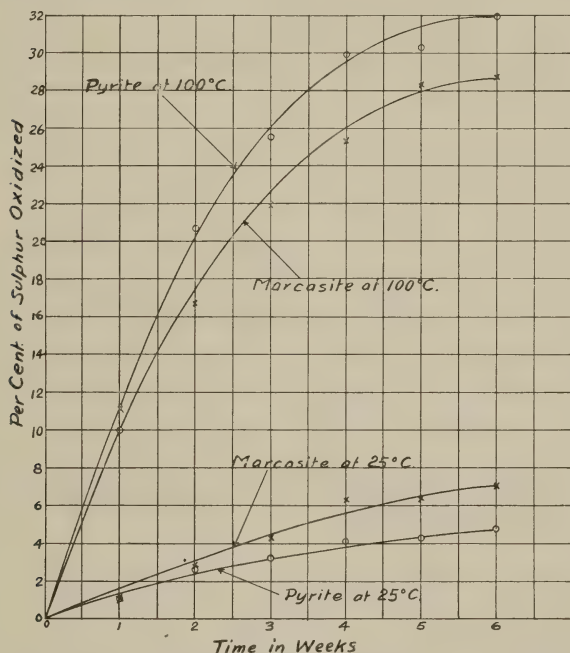


Figure 5—Comparison of Rate of Oxidation of Pyrite and Marcasite at 100° and 25° C. in Oxygen Saturated with Moisture, Both Minerals Passed through 325-Mesh Sieve

Effect of Moisture and Oxygen Concentration

In the previous experiments pure oxygen was used for oxidation for the purpose of hastening the reaction and thus reducing the time of the laboratory processes. Some experiments seem to be necessary to show the significance of concentration of oxygen and its mode of action, as well as that of moisture in the coal. Six series of experiments were carried out in this direction on Vermilion County coal. The main features of the work may be outlined as follows:

(a) Coal containing high textural moisture was oxidized with oxygen saturated with moisture.

(b) Coal containing high textural moisture was oxidized with air saturated with moisture.

(c) Coal containing high textural moisture was oxidized with laboratory air unsaturated with moisture.

(d) Coal was dried in the laboratory air until its moisture equilibrium was established and then oxidized with oxygen saturated with moisture.

(e) Coal was dried as in (d) but was again sprinkled with water on the surface by means of an atomizer and then oxidized with oxygen saturated with moisture.

(f) Coal containing its original textural moisture was subjected to slight pressure (about 15 inches of water) under oxygen for one week with the idea of letting the coal absorb as much oxygen as possible. Then the samples were stoppered in bottles and set aside. After each week determination of sulfate content was made on duplicate samples.

The results of this series of tests are represented in Figure 9. It will be noted that when air is used instead of oxygen

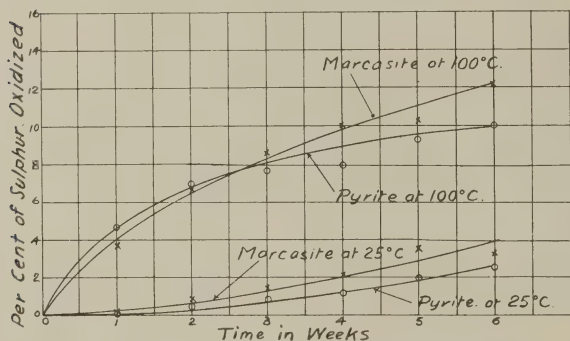


Figure 6—Comparison of Rate of Oxidation of Pyrite and Marcasite at 100° and 25° C. in Oxygen Saturated with Moisture, Both Minerals Passed through 140-Mesh and Caught on 80-Mesh Sieve

the rate of oxidation is reduced to about half of that for corresponding values with oxygen. In series (c), where the air was not saturated with moisture, the amount of which depends on the relative humidity being fairly low in the laboratory atmosphere, the oxidation of pyrite was slow or practically negligible after the first week. The sulfate formed during the first week was derived from the moisture originally present in the coal.

Series (d), (e), and (a) demonstrate clearly the effect of the moisture content of the coal on its textural condition. The removal of initial moisture from the coal decreases the rate of oxidation of sulfur, especially at the first stage. As the oxidation goes on, when enough moisture is absorbed into the coal the normal rate gradually recovers. Rewetting after drying does not restore the original speed quickly, the difference being probably due to uneven distribution of the moisture. After several weeks the moisture is more uniformly

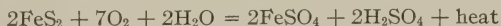
distributed, and the oxidation goes on with its original rapidity or the rate may even be higher.

In series (f) we provide another set of conditions for the oxidation of the sulfur. All the initial moisture is retained, plenty of oxygen is absorbed into the coal mass, and in addition there are a few cubic centimeters of oxygen above the surface of the coal in the bottle. Everything that is necessary for the oxidation is present in a confined space; yet the oxidation goes on with extreme slowness. During the week when the samples were under oxygen pressure, there was only 2.39 per cent of sulfur oxidized as compared with 4.19 per cent when it was oxidized in a moving stream of saturated oxygen at the same temperature. Therefore, the best condition for the pyrites to oxidize is in a moving stream of oxygen saturated with moisture. High moisture in coal seems always to be accompanied by rapid oxidation of the pyrites in the coal. As the moisture in the coal evaporates oxygen moves in to fill its place. The oxygen in this stage behaves in a way similar to oxygen in the nascent state, and appears to be much more active than the ordinary form of the gas.

Discussion of Results

As indicated at the beginning of this paper, the present study aims primarily to determine the oxidation behavior of pyrites at normal temperatures. There is ample evidence to show that at higher temperatures—say 75° C.—oxidation becomes so active as to proceed rapidly to the autogenous stage. The real question involved, therefore, is—how does coal reach those temperatures above the normal in coal piles aside from external sources such as hot walls, hot pipes, etc., which may bring the mass up to the danger point? The studies here given are directly concerned with the role that pyritic sulfur may play in this direction. It has been demonstrated that pyrites will oxidize when oxygen and moisture are present. The oxidation is quite rapid under suitable conditions and enough heat may be liberated to raise the coal to the danger point.

The heat production of the oxidation of pyrites has been studied by Parr and Kressman,¹⁰ Winnill,² and Graham.³ The reaction may generally be represented by the following equation:



The further formation of ferric sulfate is generally believed improbable due to the reducing action of the carbonaceous materials present in the coal. Parr and Kressman calculated the heat produced indirectly from the heat of combustion of pyrites into ferric oxide and sulfur dioxide as determined by Sommermeier. They found that for every two molecules of pyrites oxidized there are 624 large calories of heat liberated, not taking into account the heat of solution

¹⁰ University of Illinois, Eng. Exp. Sta., *Bull.* 46 (1910).

of sulfuric acid or of the hydration of ferrous sulfate. This when figured to volume of oxygen absorbed is equivalent to 4.1 calories for every cubic centimeter of oxygen absorbed. This calculation was confirmed by Winmill, who found by actual determination, 4.3 calories evolved for every cubic centimeter of oxygen absorbed.

Let us now take one instance from this investigation and figure out its thermal effect, approximately as nearly as possible the actual conditions on the coal piles. Vermilion County coal contains 3.75 per cent of sulfur and we may assume an oxidized condition of about 20 per cent. Suppose

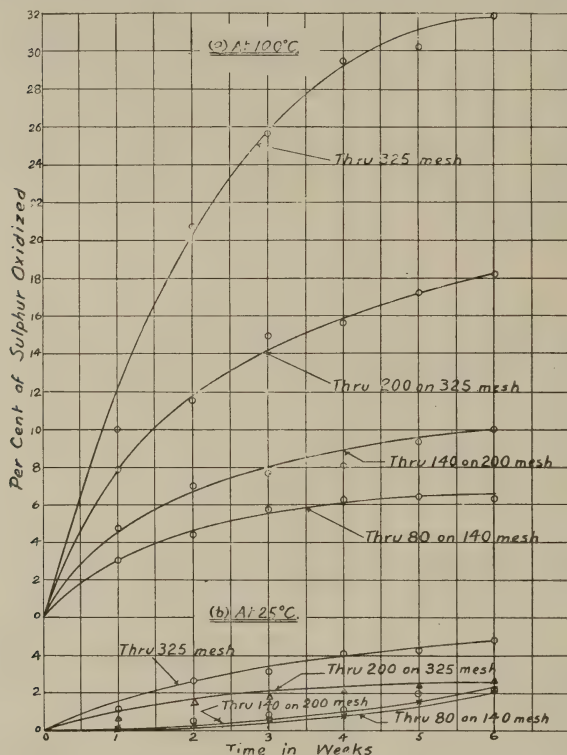


Figure 7—Oxidation of Pyrite at 100° and 25° C. in Oxygen Saturated with Moisture

that the coal pile contains a layer of fines which in turn contains about 50 per cent of finer stuff of the same degree of fineness as the samples used for the experiments. The dilution would probably decrease the heat effect on the temperature of the coal also about 50 per cent. Take 1 kg. of the coal into consideration; this amount of coal contains 37.5 grams of sulfur. At the end of 6 weeks 20 per cent, or .75 grams, of it is oxidized. This amount of oxidation will evolve 37.6 large calories of heat. The specific heat of coal was first roughly determined by Trefall and more recently

by Coles. It was found to vary with the moisture content and the C : H ratio. In general it lies between 0.2 to 0.4, and the average value of 0.3 may be taken for illustration here. The amount of heat as obtained above will raise 1 kg. of coal $\left(\frac{37.6}{1 \times 0.3}\right)$ 125.3° C. Allowing 50 per cent due to the dilution by the coarser particles, which is assumed to be inert, we have a rise of 62.6° C. This will raise the temperature of the coal pile from 25° C. to above 85° C., which is well on the way to the danger point.

This illustration is based on the natural rate of oxidation, independent of any of the catalytic agents. Should there be some catalytic agent present, such as Indiana clay, the rate can be at least doubled and vigorous heating is sure to occur. Furthermore, this estimation is based on the rate of oxidation at 25° C., but in effect the rate is always increasing

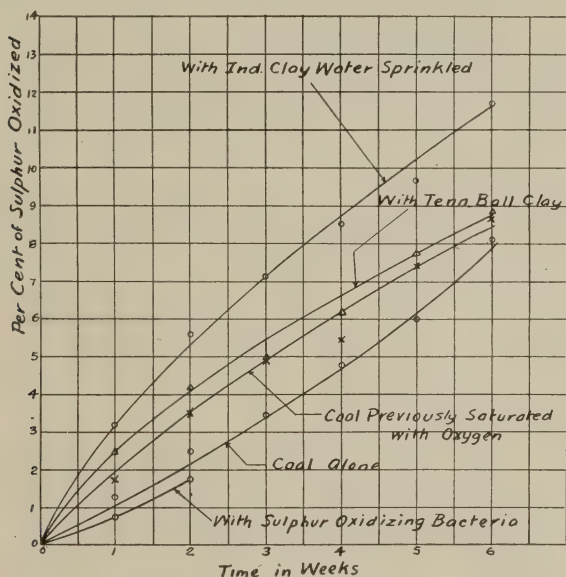


Figure 8—Oxidation of Sulfur in Jackson County Coal at 25° C in Presence of Various Catalytic Agents

gradually due to the augmentation of heat given out from the reaction, if it is not dissipated. If we take this into consideration, the estimation would be too low. The accelerating effect of increased temperature might more than offset radiation losses.

Coals may also contain a pocket or lens of pyrites in a finely divided condition. This would certainly make a hot spot in the coal pile and its ignition action would be probable. Of course the behavior of pyrites in coals differs widely, as shown by the first part of this investigation. Some oxidize very rapidly and others are much more inert. Some coals have low sulfur content and the rate of oxidation of the

latter may also be slow. In such a case the self-heating, should it happen in the coal, must be traced to the oxidation of carbonaceous material. On the other hand, in high-sulfur coal the pyrites may be a contributing cause for heat generation. In certain cases, indeed, pyrites may be the chief cause while in other cases the carbonaceous material may be active. Should they both be operative in the same coal they may each contribute to the final heating. Previous reports may sometimes have been mistaken in stating that pyrites could not be the cause of spontaneous combustion of coal because some coals had ignited with very low sulfur content; others which say that the heat resulting from the oxidation of pyrites is not enough to raise the tem-

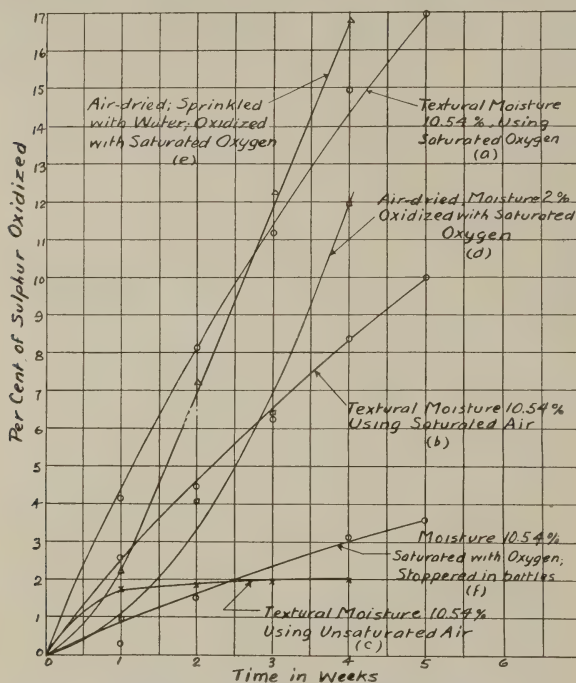


Figure 9—Oxidation of Sulfur in Vermillion County Coal at 25° C. with Varying Conditions of Oxygen and Moisture

perature of the coal to ignition may also be in error. Coal is a very complicated substance and its characteristics vary widely according to its origin and types. Many factors enter into the heating of coal; each may contribute a certain part and cooperate with the others in the development of initial heat.

Summary and Conclusions

1—Under suitable conditions the pyrites in coal will oxidize rapidly and may be a dominating factor in certain cases for the self-heating of coal.

2—Marcasite and pyrite oxidize with about the same rate, but the former breaks down more easily producing fine particles, thus facilitating its oxidation.

3—The rate of oxidation of pyrite or marcasite is directly proportional to temperature and inversely proportional to the diameter of the particles.

4—Dry air or oxygen does not promote the oxidation of the pyrites.

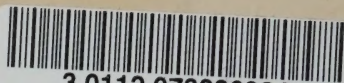
5—High textural moisture seems to be accompanied by rapid oxidation of the pyrites. A moving stream of oxygen saturated with moisture seems also to be the best accompaniment for the oxidation of pyrites in the presence of high textural moisture. The fact that high textural moisture promotes oxidation of pyrite is presumably due to the evaporation of the moisture and its subsequent replacement by oxygen. The oxygen in this state appears to be much more active than under ordinary conditions. There may be a catalyzing effect set up by this interchange of moisture and oxygen or a possible activation of the coal surfaces which results in a greater activity being imparted to the oxygen.

6—The catalytic oxidation of certain substances such as Indiana clay is presumably due to the presence of a certain type of bacteria in the clay. That the catalytic action is not from the colloidal nature of the clay alone seems evident from a comparison of the experiment with ball clay, which probably contains more of the colloidal material, yet does not produce so much catalytic action.

VITA

The writer of this thesis was born in I'hing, Kiangsu, China, February 1, 1898. Following his primary school training, he entered the Fifth Provincial Middle School at Chang Chow, Kiangsu, China, and graduated after a four years course in 1917. He entered the University of Nanking, at Nanking, China, in the fall of 1917, registering in the College of Agriculture. After three years at Nanking, he came to the United States and entered the University of Michigan, registering in the course of chemical engineering. He was at Michigan for one semester and then transferred to the University of Illinois, and graduated from the course in chemical engineering in 1922. In the fall of 1922 he took up graduate work in the department of Chemistry of the University of Illinois and has continued in the work until the present time. He received the degree of M. S. in Chemistry in 1923.

While in attendance at the University of Illinois he has held the position of Graduate Research Assistant in Chemical Engineering from 1923 to date.



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